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ENERGY BALANCE OF SOLAR HYDROGEN THE ECO-HOUSE

Tj. Marnoto[1), Kamaruzzaman Sopian[2), Wan Ramli Wan Daud[3)
[1)Department of Chemical Engineering, FTI, UPN "Veteran" Yogyakarta.
[2)Department of Mechanical and Materials Engineering
[3)Department of Chemical and Process Engineering
Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor.

Abstract

Energy system of the future will have to be cleaner and mach more efficient, flexible and reliable. Hydrogen is a clean and sustainable form of energy that can be used in mobile and stationary applications and is answer to satisfying many of our energy needs while reducing carbon dioxide and other greenhouse and gas emissions. The paper presents the power and mass balance of **Eco-House Solar Hydrogen Energy system (ECO-House SHES).** These will pave the way to study of electrolyzer, fuel cell, photovoltaic performance, and also a futuristic sustainable, environment friendly and bioclimatic residential dwellings. Sunlight hits the photovoltaic panels, which convert solar energy into DC electricity. Inverter will convert DC electric to AC electric, and this electricity will be used to run electrolyzer, and over current connected to grid. The hydrogen product of electrolyzer is stored in a storage tank at 150-200 psi pressure. The hydrogen will be converted to electricity by fuel cell unit, and also can supply fuel to household appliances. A data acquisition unit will take data of ambient temperature, PV cell temperature, Wind speed, air humidity, solar radiation, voltage and current of PV, connect to grid, to electrolyzer unit and electrolyzer cells stack, and electrical product of Fuel cell unit. Also flow rate hydrogen product of electrolyzer, hydrogen consumed of Fuel cell unit. The objective is to improve the efficiency of the solar hydrogen energy system and it reliability.

:ey word: Solar, Hydrogen, Energy system, Photovoltaic, Fuel Cell, Electrolyzer.

. Introduction

Energy supply systems based on renewable such as solar radiation requires energy storage to match the onuniform or sometimes anticyclical profile of power generation and power demand. Design and operation of ıese new energy systems raise new challenges because renewable energy conversion, storage and consumption ave to be harmonized. Seasonal energy storage is a necessity for widespread renewable energy (RE) utilization ıd hydrogen (H2) based technologies offer a promising alternative to achieve it.

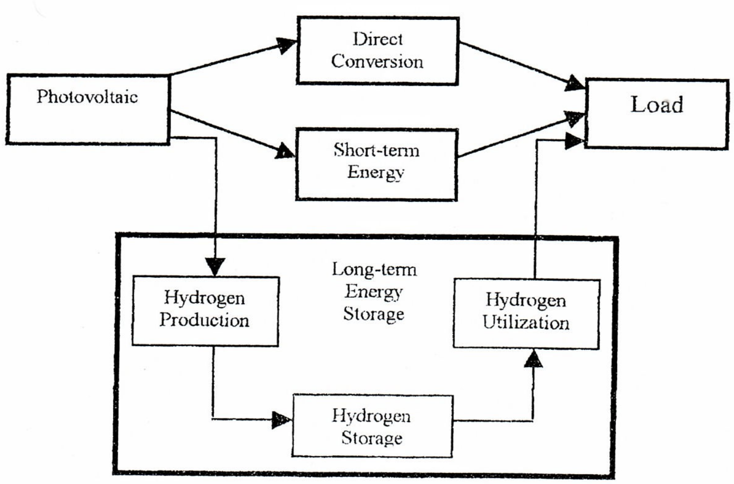


Fig 1: Schematic of Solar Energy System

stand-alone RE system, based on the storage of energy in hydrogen, includes booth sort-term and long-term stems, each with its own devices. Hydrogen has special long-term storage advantages due to its inherent high ıss energy density. (Kodjo Agbossou et. al.; 2004). Researchers have done similar experimental study and

simulation works on Solar Hydrogen Energy, among other things: J.P Vanhanen and P.D. Lund; 1994; A. Szyszka C., 1998; Meurer. Et. al., 1999; S.R. Vosen, and J.O. Keller,1999; P.C. Ghosh, 2003; Kodjo Agbossou et. al.; 2004)
This study special compared to other studies is that, there is hydrogen fuel for household need like cooking stove, and other requisite. The objective is to improve the efficiency of the solar hydrogen energy system and it reliability.

2. ECO-house Solar Hydrogen Energy

The Eco-house SHES is constructed in a location where it would get an optimum solar radiation for a maximum electricity production, 42 multi-crystal photovoltaic (PV) panels are mounted on the rooftop of the Eco-house, to give peak power of 5 kW. An Electrolyzer subsystem, which has capacity of 19 standard cubic feet per hour (scfh) of hydrogen production, is used to transformed electrical energy into chemical energy in the form hydrogen. Produced hydrogen gas is stored in a 1500 liter cylinder pressure tank while the oxygen gas is vented out. A 1 kW Fuel cell subsystem will be installed, to used to convert chemical energy into electrical energy, and also hydrogen stove will be installed in the Eco-house kitchen for cooking. A data acquisition system will take data of ambient temperature, PV cell temperature, Wind speed, air humidity, solar radiation, voltage and current of PV, connect to grid, to electrolyzer unit and electrolyzer cells stack, and electrical product of Fuel cell unit. Also flow rate hydrogen product of electrolyzer, hydrogen consumed of Fuel cell unit, and hydrogen supply of household.

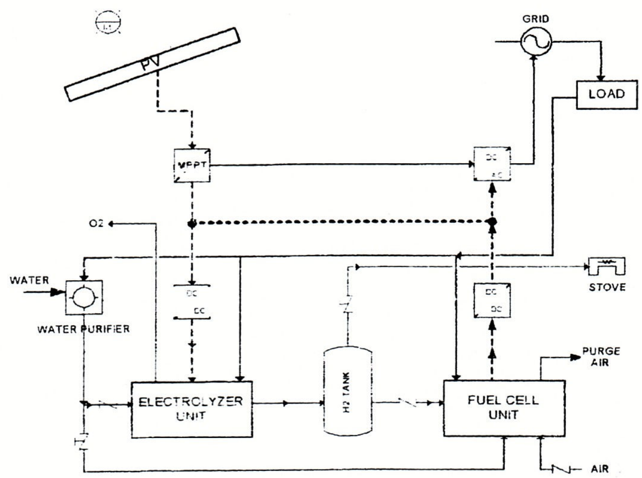


Fig. 2: Schematic of Eco-House SHES

3. Power and gas balance

Solar radiation measured by pyranometer is expressed in E_{TT} W / m^2, hence power sunlight of certain a time gap:

Solar power: $$P_{Sd} = \sum_{t_0}^{t_n} E_{TT}.A_{pv} = A_{pv} \int E_{TT}.dt$$

$$P_{Sd} = A_{pv} \int_{t_0}^{t_n} E_{TT} dt \qquad \text{(kW/day)}$$

Power electric energy of PV module: $$P_{PV,d} = \int_{t_o}^{t_n} V_{PV}.I_{PV}.dt.$$

Electric efficiency of PV module: $$\eta_{PV} = \frac{P_{PV,d}}{P_{Sd}}$$

DC Electric for PV module will be a convert to AC electric, by inverter:

$$P_{inv} = V_{inv}.I_{inv} \qquad P_{inv,d} = \int_{t_0}^{t_n} V_{inv}.I_{inv}.dt$$

$$\eta_{inv} = \frac{P_{inv,d}}{P_{PV,d}}$$

part electrical power used direct to load, and partly to input power of the electrolyzer.

$$P_{in,el} = P_{inv} - P_{load}.\big|_{t_0 \to t_n}$$

ɿe input power comprises the electrolysis and the parasitic power consumption of the hydrogen production ocess:

$$P_{in,el} = P_{el} + P_{pars,el}$$

ɿe parasitic power of electrolyzer can further be split into two parts:

$$P_{pars,el} = P_{ctrl,el} + P_{gh,el}$$

ɿe electrolyzer power P_{el} goes into hydrogen production and heat production:

$$P_{el} = P_{H_2,el} + P_{heat,el}$$

$$P_{H_2,el} = N_{c,el}.U_{rev}.\eta_{el}.I_{el}$$

$$P_{heat,el} = N_{C,el}(U_{el} - \eta_{el}.U_{rev}).I_{el.}$$

$_{rev}$ is the reversible voltage electrolysis, corresponds to the upper heating value, ΔH, as follow: $_{rev} = \frac{\Delta H}{n.F}$ where n is the number electrons transferred in the electrochemical reaction, and F is the Faraday ›nstant (96.485 As.). η_{el} is the utilization factor electrolyzer, equivalent to the electrolyzer current efficiency, $\eta_{el} = \frac{C_c.\overline{Q}_{el,gr}}{N_{c,el}.I_{el}}$ where C_c is the conversion constant(2.39 A.h/1 H_2), $\overline{Q}_{el,gr}$ is the production rate hydrogen, I_{el} is e current of electrolyzer. Thus, the gross production rate of hydrogen is:

$$\overline{Q}_{el,gr} = \frac{N_{c,el}.\eta_{el}.I_{el}}{C_c} \qquad \overline{Q}_{el,gr} = \overline{Q}_{el,net} + \overline{Q}_{el,loss}$$

$_{el,loss}$, Is the hydrogen loss in the gas handling system, and $\overline{Q}_{el,net}$, is the net production rate of hydrogen.

$$P_{el,net} = U_{el}.C_c.Q_{el,net}$$

›wer efficiency of the electrolyzer is: $\eta_{p,el} = \frac{\int_{t_0}^{t_n} P_{el,net}.dt}{\int_{t_0}^{t_n} P_{in,el}.dt}$

ıseous hydrogen can be storage in pressure tank, in this study hydrogen gas assumption follow ideal gas. The ıount of hydrogen in storage is described by the hydrogen balance equation:

$$\frac{dH_2}{dt} = \overline{Q}_{el,net} - \overline{Q}_{fc,gr} - \overline{Q}_{household}$$

$$\left.\frac{dP_T}{dt}\right|_{t_0 \to t_n} = \frac{R.T_T}{V_T}(\overline{Q}_{el.net} - \overline{Q}_{fc.gr} - \overline{Q}_{household})$$

$$\int_{P_0}^{P_n} dP_T = \frac{R.T_T}{V_T}\int_{t_0}^{t_n}(\overline{Q}_{el,net} - \overline{Q}_{fc,gr} - \overline{Q}_{household}.)dt$$

$$P_{T,n} = P_{T,0} + \frac{R.T_T}{V_T}\int_{t_0}^{t_n}(\overline{Q}_{el,net} - \overline{Q}_{fc.gr} - \overline{Q}_{household}).dt$$

$$P_{household},d = \Delta H.\int_{t_0}^{t_n} Q_{household}.dt$$

here $\overline{Q}_{fc,gr}$, is the gross consumption hydrogen rate of fuel cell, $\overline{Q}_{household}$ is the hydrogen supply of usehold appliances.

$$P_{H_2.fc} = Q_{fc.gr}.\Delta H \qquad \overline{Q}_{fc,gr} = \overline{Q}_{fc,cons} + \overline{Q}_{fc,loss}$$

$$P_{H_2,cons} = P_{fc} + P_{heat}$$

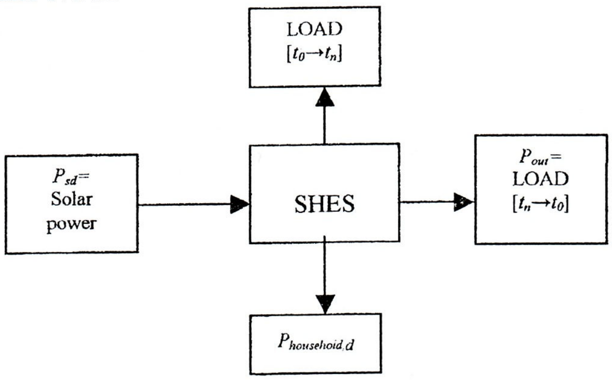
$$P_{fc} = P_{out} + P_{pars} = P_{out} + P_{ctrl} + P_{hand}$$

$$P_{hand} = P_{airComp} + P_{W,Pump} + P_{fan,C}$$

$$P_{out} = P_{fc} - P_{ctrl} - P_{airComp} - P_{W,pump} - P_{fan,C}$$

$$\eta_{fc} = \frac{\int_{t_n}^{t_0} P_{out}.dt}{\int_{t_n}^{t_0} P_{H_2,fc}dt}$$

Power and gas balance overall:



The overall power efficiency: $\eta_{OP} = \dfrac{P_{load}\big|_{t_0 \to t_n} + P_{household.d} + \int_{t_n}^{t_0} P_{out,fc}}{P_{sd}}$

4. **Photovoltaic Array**

A solar photovoltaic system requires a maximum-power-point tracking (MPPT) to control the PV arrays to operate at the maximum-power point (MPP) to achieve the best power generation efficiency The Eco-House SHES use Solar Grid Interactive Sine Wave Inverter, include of Maximum Power Point Tracking. The Inverter and Photovoltaic specification is shown in Table 1. B.Ai. et. Al., 2003, present of the characteristic equation of PV module with assuming that maximum power point tracker (MPPT) is used and the PV module is always working at the maximum power point, the formula for calculating the optimum operating point current and voltage under arbitrary conditions have the following forms:

$$I_{PV} = I_{SC}\left\{1 - C_1\left[\exp\left(\frac{V_{PV} - \Delta V}{C_2 V_{OC}}\right) - 1\right]\right\} + \Delta I$$

$$C_1 = \left(1 - \frac{I_{MP}}{I_{SC}}\right)\exp\left(\frac{-V_{MP}}{C_2.V_{OC}}\right) \qquad C_2 = \frac{V_{MP}/V_{OC} - 1}{\ln\left(1 - I_{MP}/I_{SC}\right)}$$

$$V_{PV} = V_{MP}\left[1 + 0.0539.\log\left(\frac{E_{TT}}{E_{ST}}\right) + \beta_0.\Delta T\right]$$

$$\Delta V = V_{PV} - V_{MP} \qquad \Delta I = \alpha_0\left(\frac{E_{TT}}{E_{ST}}\right)\Delta T + \left(\frac{E_{TT}}{E_{ST}} - 1\right)I_{SC}$$

$$\Delta T = T_{Cell} - T_{ST} \qquad T_{Cell} = T_A + 0.02.E_{TT}$$

Where: β_0 is Module voltage temp coefficient; α_0 is Current Temperature coefficient; I_{PV} , module optimum operating point current at arbitrary condition (A); I_{SC} , module short circuit current (A); V_{PV} , module optimum operating point voltage at arbitrary condition (V); V_{OC} , module open circuit voltage (V); I_{MP}, module maximum power current (A); V_{MP}, module maximum power voltage (V); E_{ST}, standard light intensity (1000 W/m^2); E_{TT}, total irradiance incident on titled plane and horizontal surface (W/m^2); T_{ST}, Standard temperature (25^{o} C); T_{Cell}, Cells temperature (^{o} C); T_A, ambient temperature at arbitrary condition (^{o} C).

Table 1 : Inverter and Photovoltaic Specification

INVERTER	
Input Voltage	110 V
Operating DC Voltage range	98 – 168 V
Input Voltage and frequency	240V, 50/60 Hz
MPPT working range	105 – 155 V, DC
Continuous output @ 40C	5 kW
Peak efficiency	94%
Off line losses	15 W
Weight	70 Kg.
PHOTOVOLTAIC	
Total Capacity (42 panel)	5 kW
Maximum Power output	35 Watts
Maximum Power Voltage	16.9 V.
Maximum Power Current	7.10 Amp.
Open Circuit Voltages	21.5 V
Short Circuit Current	7.45 Amp.
Voltage temp. Coefficient (β_0)	-0.1152 V/°C
Current Temperature coefficient (α_0)	0.000124 A/°C
Length	1425 mm
Width	652 mm
Depth	52 mm

Hydrogen Production

The HOGEN RE hydrogen generator produces hydrogen; it is fully integrated that produces hydrogen from ıter and electricity. The system includes an electrolyzer cell stack, as well as all the auxiliary equipment cessary for regulating electrolyzing operation and pressurizing hydrogen. The Electrolyzer specification is ɔwn in Table 2. The characteristic current–voltage (I –V) curve considered for the electrolyzer (Massimo ntarelli, et.al, 2004), is:

$$V_{el} = V_0 + b\ln\left(\frac{I}{I_0}\right) + R.I$$

ıere: Reversible voltage (V_0) =1.189 V; Coefficient of Tafel line (b) = 0.4857 V, Exchange current (I_0) = ›46 A, Cell resistance (R) =48.5E-6 Ω

Table 2: Electrolyzer Specification

Electrolyte	Photon Exchange Membrane (PEM)
Production rate	19 scfh Hydrogen
Max. Delivery pressure	200 psig.
Hydrogen purity	>99.99 %.
Feed water quality	Deionised per ASTM Type II
Input AC power	190-140 V AC, 1 phase 50/60 Hz.
Input DC power	60-240 V DC.
Operating condition	5-50°C, 0-95% Humidity.
Dimension	785 x 968 x 1052 mm

Hydrogen Conversion.

The hydrogen is converted back into electricity in a fuel cell stack, in which hydrogen and oxygen react ɔtrochemically to form water and electricity. The fuel cell modeled is a PEM; it uses air and hydrogen nidified to 80°C in two gurgle tanks to hydrate the Nafion membrane. The characteristic current–voltage (I – of a unit fuel cell can be modeled (Massimo Santarelli, et.al, 2004), as follows:

$$V_{fc} = E_r - (i - i_n)r - A\ln\left(\frac{i + i_n}{i_0}\right) + B\ln\left(1 - \frac{i + i_n}{i_l}\right)$$

$$P_{fc} = N_{c,fc}.I_{fc} \qquad I_{fc} = A_{c,fc}.i$$

ere: Reversible voltage (V_r)=1.2 V, Internal and fuel cell crossover equivalent current density(i_n) =2 /cm2., exchange current density(i_0) =0.067 mA/cm2, limiting current density (i_l)= 900 mA/cm2, Constant of ėl overpotential (A) =0.06 V, Constant of diffusion overpotential (B)=0.05 V, Area specific area (r)=30E-6 ɔm2.

7. Hydrogen Stove.

Hydrogen burns differently than either propane or natural gas. In particular, hydrogen's rate of diffusion and flame velocity are roughly ten times or greater than that of propane or natural gas. Flashback of the flame into the primary mixture of fuel gas and air must be prevented in all burners. Fortunately, preventing hydrogen from mixing with air before the burner port can minimize flashback. Heat of hydrogen combustion is: $P_{H_2,C} = m_{H_2}\Delta H_C$.

8. Summary.

Mathematical methods for an Eco-House SHES have been described to get closer insight into system operation. The main result is summarized as follows:

- Power and gas balance were used to describe the power chain from energy input to energy output. By using equation presented, the total efficiency of the system can be calculated.
- The efficiencies of the whole hydrogen production and conversion subsystem must consider parasitic power consumption, hydrogen losses in order to describe the overall performance hydrogen production and subsystem conversion
- The electrochemical characteristics of the components are the most significant factor influencing the total efficiency of system. However losses in the process control and gas handling system need to be considered carefully in small application.
- The hydrogen used direct burns, or use hydrogen as fuel for household need like cooking stove, and other requisite, can increasing of total efficiency of system.

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